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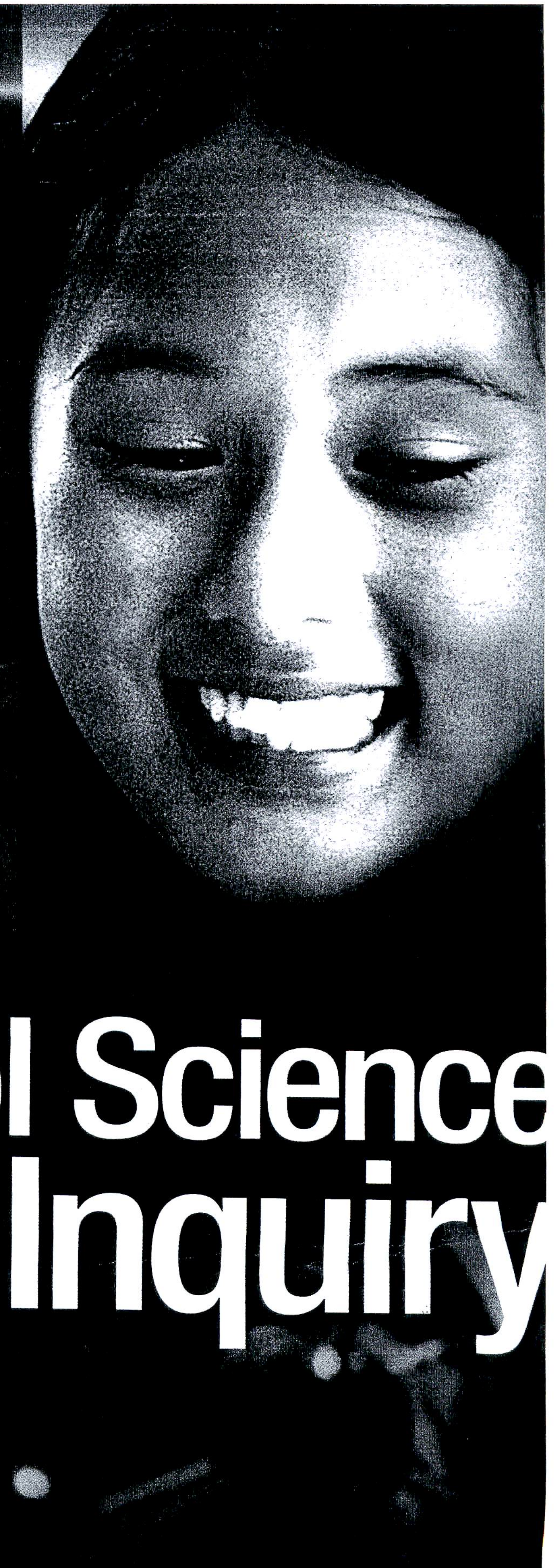

TEACHING High School Science Through Inquiry

A CASE STUDY APPROACH

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1

Constructing an Understanding of Scientific Inquiry

The pebble that drops into a pond is like an idea that sparks inquiry. The concentric ripples represent new questions that emerge from the first germ of the idea. The ever-enlarging pattern of ripples refer to the integrated knowledge that is acquired as each question is explored, limited only by the force of the inquirer's enthusiasm for the search. The greater the interest and the more probing the questions, the more encompassing the study, the bigger the ideas that it develops, and the deeper and more meaningful the knowledge the inquirer constructs.

—From *Interdisciplinary Inquiry in Teaching and Learning* by Marian Martinello and Gillian Cook (1990)

A CULTURE OF INQUIRY

One of the most talked about topics in science education today is scientific inquiry. Whether you are discussing science literacy, standards, instructional strategies, or assessment, the phrase "scientific inquiry" likely will work its way into the conversation. Thus, for many teachers, constructing an understanding of scientific inquiry becomes a primary necessity to contributing to an articulate discussion on science education. The primary purpose of this book is to enable high school science teachers not only to develop an understanding of scientific inquiry but also to gain an appreciation of the skills, dispositions, and attitudes in creating a "culture of inquiry" within themselves as well as their classrooms. According to Reagan, Case, and Brubacher (2000):

> A culture of inquiry, in short, entails not merely teachers engaged in inquiry but teachers and others collaboratively and collegially seeking to understand better and thus improve aspects of the schooling experience. For a culture of inquiry to exist and be maintained in a school, an on-going commitment to valuing curiosity, mutual respect, and support among teachers and between teachers and administration, a willingness to try new ideas and practices, and the ability to remain open to the unforeseen and unexpected are required. (p. 43)

As you journey through this book, reflect on your classroom norms and practices, share your ideas with a colleague, and keep a journal of your thoughts and progressive gains. Reflection and dialogue, especially with others who are seeking and committed to the same instructional practices as you, are important aspects of becoming an inquiry-based teacher.

Inquiry and Habits of Mind

Scientific inquiry provides an excellent means to foster the development of students' habits of mind. Marzano (1992) describes habits of mind as mental habits individuals develop to render their thinking. Habits of mind often encompass higher-order thinking skills, critical and scientific reasoning skills, problem-solving skills, communication and decision-making skills, and metacognition—being aware of your own thinking. Costa and Kallick (2001) describe habits of mind as "having dispositions toward behaving intellectually when confronted with problems, the answers to which are not immediately known" (p. 1). Although examples of habits of mind vary from author to author, the attributes usually common in science include the following:

- Commitment
- Creativity
- Curiosity
- Diligence
- Fairness
- Flexibility
- Imagination
- Innovation
- Integrity
- Openness
- Persistence
- Reflection
- Sensitivity
- Skepticism
- Thoughtfulness

As we journey further into our understanding of inquiry, we will come to see how inquiry-based classrooms promote critical thinking skills and habits of mind, as well as how these classrooms empower students to become independent, life-long learners. Hester (1994) tells us that inquiry involves

> critical thinking processes such as methods of diagnosis, speculation and hypothesis testing. The method of inquiry gives students the opportunity to confront problems, and generate and test ideas for themselves. . . . The emphasis is on ways of examining and explaining information (events, facts, situations, behaviors, etc.). Students when taught for the purposes embodied in inquiry are encouraged to evaluate the usefulness of their beliefs and ideas by applying them to new problem situations and inferring from them implications for future courses of action. (pp. 116–117)

The *Benchmarks for Science Literacy* (AAAS, 1993) suggests that "by the end of the 12th grade, students should know why curiosity, honesty, openness, and skepticism are so highly regarded in science and how they are incorporated into the way science is carried out; exhibit those traits in their own lives and value them in others" (p. 287). According to the AAAS (1993), "taken together, these values, attitudes, and skills can be thought of as habits of mind because they all relate directly to a person's outlook on knowledge and learning and ways of thinking and acting" (p. 281).

Why are habits of mind important to inquiry? As students engage in scientific inquiry, they demonstrate these attributes and behaviors in a collective sense as part of completing the task. According to the AAAS (1990):

> It is also important for people to be aware that science is based upon everyday values even as it questions our understandings of the world and ourselves. Indeed, science is in many respects the systemic application of some highly regarded human values. . . . Scientists did not invent any of these values . . . but the broad field of science does incorporate and emphasize such values and drastically demonstrates just how important they are for advancing human knowledge and welfare. Therefore, if science is taught effectively, the results will be to reinforce such generally desirable human attributes and values—curiosity, openness to new ideas, and skepticism. (p. 185)

Wilks (1995) suggests that "the use of philosophical inquiry as a means of developing the skills of dialogue and thinking involves the teachers and their students becoming cooperative and caring co-inquirers working together in a community of inquiry" (p. 1). Wilks further comments that "a community of inquiry emerges from frequent group discussions fostered by teachers who are committed to the process of inquiry" (p. 4).

WHAT SCIENCE EDUCATORS SAY ABOUT INQUIRY

As we look toward the science educators who have devoted their professional career to studying scientific inquiry, several common themes surface. Whether the experts represent K–12 educators, higher education faculty, or the staffs of hands-on museums and national organizations, they concur that scientific inquiry focuses on the engagement of students to generate and pursue the answers to questions through careful observation and reflection.

The Center for Inquiry Based Learning (CIBL) at Duke University (www.biology.duke.edu/cibl/index.htm) provides useful definitions and information about inquiry. Hebrank (2000), a CIBL teacher, says:

> Inquiry is a way of acquiring knowledge. In inquiry-based learning, students either ask their own questions or are posed a question by the teacher. In the former case the question concerns a topic the students wish to learn about, and in the latter case the question concerns a topic the teacher wishes students to learn about. Regardless of the source of the question, inquiry-based learning requires that students play a major role in answering the question. (n.p.)

This definition, like others, stresses the role of the student as a researcher. In inquiry-based learning, the emphasis is placed on the student as an active investigator. Writing for *The Science Teacher,* Edwards (1997) says, "to have bona fide inquiry experiences, students must formulate their own questions, create hypotheses, and design investigations to test the hypotheses and answer the questions proposed" (p. 18).

Based on these thoughts, inquiry is a *means* as well as an *end* (Hackett, 1998). "In the *Standards,*" according to Hackett, "the term 'inquiry' is used in two different ways. First, inquiry refers to teaching methods and strategies. Second, the *Standards* identify scientific inquiry as content that students should understand and be able to do" (Hackett, 1998, p. 35). Similarly, in *A History of Ideas in Science Education* (DeBoer, 1991), inquiry is seen as a product as well as a process in science education.

Chiappetta (1997) also stresses the dual role of inquiry. "In contrast to teaching science *by* inquiry (general inquiry) is the notion of teaching science *as* inquiry (scientific inquiry). Teaching science as inquiry stresses active student learning and the importance of understanding a scientific topic. Here content becomes a critical aspect of the inquiry" (Chiappetta, 1997, p. 23).

Finally, for a complete and comprehensive literature review of scientific inquiry, see the Northwest Regional Educational Laboratory Program Report *Science Inquiry for the Classroom* (Hinrichsen & Jarrett, 1999), available online through www.nwrel.org/msec/images/science/pdf/litreview.

WHAT THE *NATIONAL SCIENCE EDUCATION STANDARDS* SAY ABOUT INQUIRY

In 1996, the National Research Council (NRC) released the *National Science Education Standards* (*NSES*). In regard to the inquiry standards, the NRC states:

> Inquiry is a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known in light of experimental evidence: using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations. (p. 23)

However, according to the *Standards,* doing inquiry involves more than just utilizing science process skills in the classroom. The *Standards* requires that high school teachers plan activities that engage students in combining process skills and critical reasoning skills to develop an appreciation for and understanding of science. According to the *Standards* (NRC, 1996), engaging high school students in inquiry helps develop

- an understanding of scientific concepts,
- an appreciation of "how we know" what we know in science,
- an understanding of the nature of science,
- skills necessary to become independent inquirers about the natural world, and
- the dispositions to use the skills, abilities, and attitudes associated with science.

The *Standards* also highlights the ability to conduct inquiry and develop an understanding about scientific inquiry:

> Students in all grade levels and in every domain of science should have the opportunity to use scientific inquiry and develop the ability to think and act in ways associated with inquiry, including asking questions, planning and conducting investigations, using appropriate tools and techniques to gather data, thinking critically and logically about the relationships between evidence and explanations, constructing and analyzing alternative explanations, and communicating scientific arguments. (NRC, 1996, p. 105)

The inquiry standards set forth by the NRC (1996) are divided into three separate sets of grade levels or junctures. Each juncture identifies inquiry standards specific for that set of grade levels. These standards help science educators to define what students should know and be able to do. Reading the inquiry standards for grades 9–12 can help develop an understanding of the abilities necessary to do scientific inquiry.

At the high school level, according to the NRC, students should be able to

- identify questions and concepts that guide scientific investigations,
- design and conduct scientific investigations,
- use technology and mathematics to improve investigations and communications,
- formulate and revise scientific explanations and models using logic and evidence,
- recognize and analyze alternative explanations and models, and
- communicate and defend a scientific argument. (NRC, 2000a, p. 19)

Science teachers should become familiar with the *National Science Education Standards.* The *Standards* can be purchased in softcover, read online, or downloaded from the National Academies Press (www.nap.edu/bookstore.html). Readers may also be interested in an excellent accompanying text, *Inquiry and the National Science Education Standards: A Guide for Teaching and Learning* (2000a), that offers stories of high school teachers engaging students in inquiry (see Resource A, the "Print Resources on Inquiry" section).

WHAT THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE SAYS ABOUT INQUIRY

In 1990, the AAAS published the first of two documents, *Science for All Americans,* which outlined a long-term view for instructional reform in science. It also marked the beginning of Project 2061 by the AAAS, which proposed recommendations for moving toward the goal of nationwide scientific literacy by 2061 (the year of the return of Halley's Comet). Following *Science for All Americans*, in 1993, the AAAS released *Benchmarks for Science Literacy.* It did not define curricular needs but identified specific outcomes for science education and, like the *NSES*, provided local school districts, state education agencies, and national science educational organizations with a blueprint for systemic reform.

Like the *National Science Education Standards*, Project 2061 addressed the need for integrating scientific inquiry and content. The AAAS (1993) describes scientific inquiry as being

> more complex than popular conceptions would have it. It is, for instance, a more subtle and demanding process than the naive idea of making a great many careful observations and then organizing them. It is far more flexible than the rigid sequence of steps commonly depicted in textbooks as the scientific method. It is much more than just doing experiments, and it is not confined to laboratories. If students themselves participate in scientific investigations that progressively approximate good science, then the picture they come away with will likely be reasonably accurate. But that will require recasting typical school laboratory work. The usual high school science "experiment" is unlike the real thing. The question to be investigated is decided by the teacher, not the investigators; what apparatus to use, what data to collect, and how to organize the data are also decided by the teacher (or the lab manual); time is not made available for repetitions or, when things are not working out, for revising the experiment; the results are not presented to other investigators for criticism; and, to top it off, the correct answer is known ahead of time. (p. 9)

Like the NRC (1996) *Standards*, the AAAS's (1993) *Benchmarks* is divided into separate grade levels or junctures. According to the AAAS, by the end of 12th grade, students should know the following:

- Investigations are conducted to explore new phenomena, validate previous results, test predictions, and compare theories.
- Hypotheses are used in science for guiding the interpretation of data.
- Scientists control conditions (of an experiment) in order to obtain evidence.
- Science depends upon intelligence, hard work, imagination, and even chance.
- Scientists check each other's results to prevent bias.
- New ideas often encounter criticism and are limited by the context in which they were conceived. (p. 13)

Reading the high school level inquiry statements from *Benchmarks for Science Literacy* is strongly recommended. They can be purchased through or downloaded

from the AAAS Web site (www.project2061.org/tools/bsl/default.htm). You may also be interested in an accompanying AAAS text, *Inquiring Into Inquiry Learning and Teaching in Science* (see Resource A, Minstrell and Van Zee, 2000, in the section "Print Resource on Inquiry").

TEN QUESTIONS ABOUT INQUIRY-BASED LEARNING

To this point, we have been learning what scientific inquiry is. Now we want to address the questions high school science teachers often ask about inquiry-based teaching and learning.

1. I have students do many labs as part of my science course. Isn't that the same as doing inquiry?

Providing students with an opportunity to do labs, especially those that are hands-on, does not necessarily mean they are doing inquiry. Many labs and textbook activities can be very structured. Labs usually provide the students with the question to investigate, what materials to use, and most of all, how to go about solving the question by listing a sequence of step-by-step procedures of the lab. In many cases, commercially produced labs even provide a chart or table for the students to record their observations, measurements, or data. These types of labs are often referred to as "cookbook" because they provide a systematic procedure and follow a very linear path to a solution to the question. This is not to say that these kinds of lab experiences are not important, or that high school science teachers should avoid using them, but many traditional and structured labs are not real inquiry. Although most inquiry labs and activities are hands-on, not all hands-on labs and activities are inquiry oriented.

2. In my course, I start the year off by introducing students to the scientific method, and then we use it throughout the year. Is that the same as doing inquiry?

As stated in *Standards* (NRC, 1996) and *Benchmarks* (AAAS, 1993), doing inquiry does not necessarily imply following the steps of the scientific method. Inquiry incorporates the logic of problem solving that comes from the scientific method, but not necessarily the delineated, specific steps of the scientific method. The scientific method does have a role in inquiry-based labs; however, there is more to inquiry than a sequential set of procedures. According to the NRC (1996), "the standards should not be interpreted as advocating the 'scientific method.' The conceptual and procedural abilities suggest a logical progression, but they do not imply a rigid approach to scientific inquiry" (p. 144).

Many high school science teachers begin the school year by introducing the scientific method to students. The scientific method is so important to many textbook publishers that it is predominantly introduced in the first chapter of many secondary school science textbooks! In Chapter 6, we will further discuss the role of the scientific method in inquiry-based lessons.

3. When I observe a science classroom where students learn through inquiry, the lesson appears to be unstructured and open-ended. Is that good teaching?

Quite the contrary. Experienced inquiry teachers have specific goals and objectives in mind throughout their lessons. Their skills lie in empowering the students to develop their own investigations within those goals and objectives. In some high schools, a good teacher is defined as one who keeps a classroom quiet and students consumed in *seat time*. Although no one will argue that effective classroom management skills are essential for inquiry learning, an active, student-centered classroom should not be equated with chaos or unstructured instruction. Just like during any lab activity, when students do inquiry-based science we can expect the noise level to increase somewhat. To some, inquiry may appear on the surface to be unstructured and open-ended, but as student involvement increases, so does the need for the teacher to manage classroom movement and communication. When teachers use inquiry-based strategies, they may find that teaching requires more preparation and anticipation of possible student questions than traditional labs and teaching approaches do.

Bell and Gilbert (1996) report that teachers new to inquiry often feel less in control when students move about the room, make decisions about their work, and are encouraged to challenge the work of others. Although most teachers are actually in control, they perceive otherwise. To establish inquiry-centered environments, teachers need to accept changes in their role and in the atmosphere of the classroom. In Chapter 7, we will see how good classroom management and questioning skills are a prerequisite for creating a culture of inquiry. Without good classroom management, any lab, including an inquiry-based lab, will result in a chaotic situation.

4. During my class lectures and discussions, I ask students a lot of questions. Isn't that doing inquiry?

Although valuing questions is a basic commonality in all inquiry-based classroom, the misconception held by some high school science teachers is that inquiry teaching requires that the teachers ask a lot of questions. We might recall our own experiences sitting in science lectures where the teacher fired off question after question. Asking a lot of questions does not necessarily make an inquiry lesson. Again, in Chapter 7, we will see several examples of effective questioning strategies that support inquiry settings. In inquiry-centered classrooms, teachers provide open-ended experiences that lead students to raise their own questions and design investigations to answer those same questions.

5. Can all science lessons be taught through inquiry?

Although many seasoned inquiry teachers would like to believe this is true, the fact is, a good part of the content in science, especially in the high school grades, must be learned through traditional methods such as lectures, presentations, and textbooks (Hinman, 1998). Some science lessons, because of safety reasons or availability of materials, lend themselves to more structure than others and do not provide flexibility in the procedure section of the lab. As teachers, we decide which lessons are best presented through direct instruction or a teacher-led approach, and which ones can be guided through inquiry.

6. Inquiry may be appropriate for elementary and middle school students, but how can I teach through inquiry when I am expected to get students ready to

pass a final exam at the end of the course? I do not have time for inquiry in my classes.

For many high school science teachers, lecture and discussion methods are the primary means to dispense or impart knowledge to their students. These teachers see lecturing as the most effective and efficient way to transmit large amounts of content information to their students in a relatively short period. Lecturing is also the method by which many teachers learned science when they were in high school. It is also a method by which many teachers learned science when they were studying to become science teachers. Therefore, based on prior experience, we should not be surprised that so many science classes are lecture-based.

High school science teachers often talk about the time constraint they feel they are placed under. With more and more concepts being added to the curriculum, many science teachers say they are pressed to cover a great number of concepts in a school year. It is true that inquiry-based learning takes more time; however, developing higher level thinking skills and having students pose questions, plan solutions, and gather and organize data are skills that are nurtured only over time. There are no shortcuts to developing students with critical thinking skills.

I once was told the story about a physics teacher who routinely used the first 5 minutes of class to take attendance and the last 5 minutes of class to provide students an opportunity to start on their homework. If you were to multiply 10 minutes a day by 180 days per school year, you can see that this particular teacher used 1,800 minutes a year, or 36 50-minute periods, on noninstructional procedures. In addition, this same teacher taught a 5-day unit on the latent heat of vaporization that was not part of the district's physics curriculum. To find time to do inquiry or to create an inquiry-based curriculum, teachers need to utilize their time effectively and efficiently while centering on topics and concepts at the core of the curriculum.

7. How do you assess inquiry-based learning?

Inquiry-based learning can be assessed like any other concept or topic in science; but teachers need to use alternative methods of evaluation. Popular objective-type multiple-choice questions do not adequately assess inquiry-based learning. To assess students' academic progress, inquiry-based teachers often rely on using portfolios, writing journal entries, self-evaluations, and rubrics in conjunction with objective-type questions (Texley & Wild, 1998). Examples of each of these alternative assessment measures will be presented in Chapter 8.

8. I have been teaching high school science for 25 years and have seen a lot of "bandwagons" come and go in my lifetime. Isn't inquiry the latest thing for science education?

Actually, inquiry-based instruction has an enduring historical significance in science education. Those who study the history of science education know that questioning, discovery learning, and inquiry date back to the early days of the Greek scholar Socrates. Progressive education reformer John Dewey is credited as one of the first American educators to stress the importance of discovery learning and inquiry (Dewey, 1900, 1902, 1916). In his early work, Dewey proposed that learning does not start and intelligence is not engaged until the learner is confronted with a problematic situation.

Today, on the high school level, premier biology programs like the Biological Sciences Curriculum Study (BSCS, 1970, 1997) are deeply rooted in instructional methods

of learning that stress the importance of inquiry-based instruction. In addition, inquiry has been and continues to be the philosophical foundation for many National Science Foundation (NSF) and National Science Teachers Association (NSTA) sponsored curriculum projects in biology, earth science, chemistry, and physics.

9. I see inquiry as "soft science" and not content-related. Is that true?

Inquiry, according to both *Standards* and *Benchmarks*, is one of the areas identified as content-related. That elevates inquiry to the same level as knowing the concepts, principles, laws, and theories about the life, earth, or physical sciences. According to the AAAS (1990), "science teaching that attempts solely to impart to students the accumulated knowledge of a field leads to very little understanding and certainly . . . science teachers should help students to acquire both scientific knowledge of the world and scientific habits of mind at the same time" (p. 203).

If students are to gain an appreciation for science and compete in the scientific and technically oriented society of the new millennium, they will need a curriculum that promotes active learning, problem solving, and ways to solve questions. Inquiry-based science is an effective means to enhance scientific literacy. Additional research has led to the conclusion that inquiry promotes critical thinking skills and positive attitudes toward science. Although inquiry is no panacea, it is one more strategy teachers can use, at the appropriate times, to engage students in investigations and satisfy their curiosity for learning (Haury, 1993).

10. I always thought inquiry is for high-achieving, college-bound science students. Can students with learning disabilities learn through inquiry?

The recommendations set forth by both the NRC (1996) and the AAAS (1993) apply to all students regardless of age, cultural or ethnic heritage, gender, physical condition, or academic ability, interest, or aspirations. The AAAS (1990) stresses that the recommendations apply in particular to those who historically have been underrepresented in the fields of science—mainly students of color, females, limited English proficiency students, and persons with disabilities. According to *Standards*, "given this diversity of student needs, experiences, and backgrounds, and the goal that all students will achieve a common set of standards, schools must support high-quality, diverse, and varied opportunities to learn science" (NRC, 1996, p. 221). The ability to think creatively and critically is not solely for the high-achieving student. Inquiry-based instruction can and should be done equitably at all levels.

LOOKING BEYOND

As science teachers begin to give up some of their traditional teaching methods and attempt to implement aspects of inquiry-based teaching, it is a natural tendency to exhibit a "rearview mirror" mentality. Although looking ahead, peering out the windshield in a new direction where they are going, they also constantly check the rearview mirror and see just where they have been. For that reason, teachers new to inquiry become cognizant of the new pedagogy yet still consider their previously held models of teaching. Referring to the inquiry method, Postman and Weingartner (1969) suggest, "It works you over in entirely different ways. It activates different

senses, attitudes, and perceptions: it generates a different, bolder, and more potent kind of intelligence. Thus, it will cause teachers, and their tests, and their grading systems, and their curriculums to change" (p. 27).

The great Michelangelo was said to be able to envision the image of his final sculpture in the stone block before he even started carving with a hammer and chisel. In the same light, Renoir, the French Impressionist, was able to stare at a blank canvas and see the picture he was about to paint. Like any great artist, an inquiry-based teacher needs to look beyond what the class looks like in the beginning of the school year and see the image of students working like real scientists months from now. As you look out into your classroom and see the faces of your students, what do you see?